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Bamboo chips (*Bambusa vulgaris*) as an alternative lignocellulosic raw material for particleboard manufacture

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Abstract This article validates the technical feasibility of making one layer experimental particleboard from bamboo chips bonded with UF resin. Bamboo chips were characterised by having higher length to thickness and length to width ratios and lower bulk density than industrial wood chip particles. The rate of heat transfer to the core was approximately the same in the two mats, probably reflecting the same values of bulk density between bamboo and wood chips. The results obtained in this study showed that bamboo chips can be successfully used, as an alternative lignocellulosic raw material, to manufacture P3 boards for interior fitments using a relatively low resin dosage (10% UF). The more stringent ANSI criteria, however, required 14% UF resin and 1% wax to satisfy the 8% TS criteria. Combinations of bamboo chips with industrial wood chips and application of other resin systems may be an avenue for exploration in further investigations.

Bambusspäne (*Bambusa vulgaris*) als alternatives lignocelluloses Rohmaterial für die Spanplatten-Herstellung

Zusammenfassung Dieser Artikel bestätigt die technische Durchführbarkeit, eine einschichtige experimentelle Spanplatte aus Bambusspänen herzustellen, die mit UF-Harz gebunden ist. Die Bambusspäne waren dadurch charakterisiert, dass sie größere Verhältnisse von Länge zu Dicke und Länge zu Breite sowie eine niedrigere Rohdichte besaßen als Späne für industrielle Holzspanplatten. Die Rate der Wärmeübertragung zur Kernschicht war ungefähr die gleiche in beiden Matten, und reflektierte möglicherweise die gleichen Werte der Rohdichte zwischen Bambus- und Holzspänen. Die Ergebnisse dieser Studie zeigten, dass Bambusspäne als alternatives lignocelluloses Rohmaterial erfolgreich verwendet werden können, um P3 Platten für die Innenverwendung herzustellen, indem man eine relativ niedrige Harzdosierung (10% UF) gebraucht. Die stringenteren ANSI-Kriterien jedoch verlangen 14% UF-Harz und 1% Wachs, um die 8% TS-Kriterien zufriedenzustellen. Kombinationen aus Bambusspänen mit industriellen Holzspänen und die Anwendung anderer Harzsysteme könnten ein Weg sein für weitere Untersuchungen.

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1 Introduction

The increased demands of raw materials in wood panel and pulp and paper manufacturing have led to a research of utilization potentials of substitute lignocellulosic biomass. Agricultural residues, e.g. cereal straws, or dedicated annual fibre crops grown using intensive agricultural management practices, e.g. flax (*Linum usitatissimum* L.) and hemp (*Cannabis sativa* L.), represent potential alternative sources of lignocellulosic raw materials which could supplement wood from natural and plantation forests. In Europe the interest in agricultural materials has largely been driven by agricultural policy, which has encouraged farmers to devote land to the growth of non-food crops rather than to food production. As a consequence, fibre crops have received a good deal of attention during the last 10–15 years, and the forest products industries, with their huge demand for raw materials, have been identified as potential consumers of the crop materials (Hague et al. 1998).

The purpose of this communication is to report results obtained in a study the scope of which was to evaluate the technical feasibility of making one-layer experimental particleboards from bamboo chips (*Bambusa vulgaris).*

Table 1 Dimensions of bamboo and industrial wood chips. The values shown are means from 50 samples. Standard deviations in parentheses
Tabelle 1 Abmessungen von Bambus- und industriellen Holzspänen. Die gezeigten Werte sind Mittelwerte von 50 Proben. Standardabweichungen in Klammern

Dimension	Fraction retained on 3 mm mesh		Fraction retained on 1 mm mesh	
	Bamboo	Wood	Bamboo	Wood
Length	15.6 (3.1)	13.7 (4.9)	12.5 (2.1)	9.9 (3)
Width	2.2 (0.7)	2.9 (0.9)	1.5 (0.4)	2.1 (0.9)
Thickness	0.7 (0.1)	0.9 (0.2)	0.5 (0.1)	0.6 (0.2)
Length:Width	7	4.7	8.3	4.7
Length:Thickness	22.2	15.2	25	16.5
Length:Width[1]	13	–	14	–
Length:Thickness[1]	36.4	–	38.5	–

[1] Dimensions of flax chips (Papadopoulos and Hague 2003)

2 Experimental

2.1 Raw material

The raw material for experimental particleboard was provided from a local small-scale plant, which utilises bamboo for furniture manufacture. Bamboo culms were imported from Malaysia and were approximately 3 years old. The culms were cut into slices (ca. 20 cm long) and chipped in a hammer mill. For comparative reasons, wood chips were also used. Each furnish type was screened first through a mesh with 5 mm apertures to remove oversize particles and then through a mesh with 1 mm apertures to remove undersize (dust) particles.

After screening the wood and bamboo chips were dried to 3% moisture content at 70°C. After drying the bulk density of each furnish was determined. Samples of each furnish type were also further screened over a mesh with 3 mm apertures; the dimensions of particles comprising the fractions retained on and passing through the 3 mm mesh were then determined.

2.2 Board manufacture and testing

Pre-weighed raw material was placed into a resin blending chamber equipped with a rotary arm agitator. A commercial E_1 grade urea formaldehyde (UF) particleboard resin (62.4% solids content), containing 2% (based on resin solids) ammonium chloride as hardener, was used for the manufacture of boards. The amount of resin used was expressed as a percentage of the oven dry weight of wood. Where necessary, additional water was added to bring the furnish to the target moisture content level (10%); this was done after resin application. The total blending and mixing time was 3 min. Mats were hand-formed and hot pressed at 200°C for 6 min using a maximum pressure of 3.4 MPa. Target board density was 0.75 g/cm^3 and target board thickness 17.5 mm. Three replicate panels were produced for each board type. In the cases where wax (type E538, 60% solids content) was used in the particleboard manufacture, it was applied after the resin. The mat core temperature was measured during hot pressing using a 30-gauge type-K thermocouple.

After manufacture the boards were conditioned at 20°C and 60% relative humidity. Values for internal bond (IB), modulus of rupture (MOR) and thickness swelling (TS) after 24 h water immersion were then determined according to procedures defined in the American standard for particleboards (ANSI A208.1-1998) and in the European Union standards EN 310, EN 317 and EN 319.

3 Results and discussion

3.1 Particle dimensions and bulk density of furnishes

When screened over the 3 mm mesh, more than half of the bamboo furnish was retained on the mesh. This contrasted with the results for the wood chip furnish, where less than a third was retained on the mesh.

The dimensions of bamboo and industrial wood chips and their length to thickness and length to width ratios are presented in Table 1. Bamboo particles were typically longer, thinner and narrower than the wood chips. As a result, their length to thickness and length to width ratios were typically higher than those of the wood chips. The same behaviour was also observed with flax chips, however the differences in that case were more obvious (Papadopoulos and Hague 2003). The bulk density of the bamboo furnish was determined to be approximately the same with the wood chip furnish (Table 2), whereas the bulk density of the flax was reported to be about half that of the wood chip furnish (Papadopoulos and Hague 2003).

3.2 Temperature during hot pressing

Figure 1 presents typical core temperatures in the bamboo particleboard mats and in particleboard mats made from industrial wood chips. It can be seen that the rate of heat

Table 2 Bulk density (g/cm^3) of bamboo and industrial wood chips. The values shown are means from 3 samples. Standard deviations in parentheses
Tabelle 2 Rohdichte (g/cm^3) von Bambus- und industriellen Holzspänen. Die gezeigten Werte sind Mittelwerte von 3 Proben. Standardabweichungen in Klammern

Raw material	Bulk density
Industrial wood chips	0.23 (0.010)
Bamboo chips	0.20 (0.008)
Flax chips[1]	0.09 (0.002)

[1] (Papadopoulos and Hague 2003)

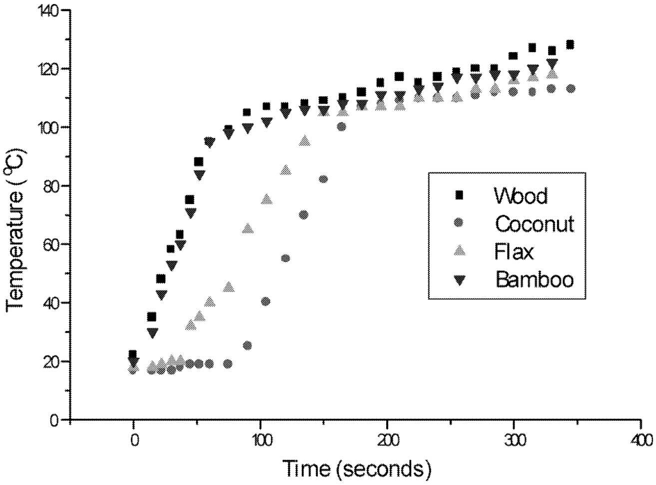

Fig. 1 Mat core layer temperature during hot pressing of test panels. Data for coconut and flax boards (Papadopoulos et al. 2002a; Papadopoulos and Hague 2003) included for comparison
Abb. 1 Temperatur der Mattenkernschicht während des Heißpressens von Versuchsplatten. Beinhaltet Daten für Kokos- und Flachsplatten zum Vergleich (Papadopoulos et al. 2002a; Papadopoulos and Hague 2003)

transfer to the core was approximately the same in the two mats, probably reflecting the same values of bulk density presented earlier. Previous studies on coconut and flax chips have shown that the rate of heat transfer to the core was significantly slower in the coconut and flax panel compared to the pure wood panel (Papadopoulos et al. 2002a; Papadopoulos and Hague 2003). This was attributed to the lower bulk density of the coconut and flax furnish and consequent reductions in mat permeability upon densification during hot pressing. This was not found to be the case in this study.

3.3 Mechanical and physical properties of panels

The properties of the single layer experimental particleboards made from bamboo chips are shown in Table 3. From this, it can be seen that higher resin content levels resulted in improved board properties. The results obtained in this study are in general agreement with those reported by Kasim et al. (2000), who successfully made particleboards from bamboo chips (*Gigantochloa Scortechinii).*

When we look at the data in light of industry standards, we see that particleboards bonded with 12% resin conformed to the more stringent requirements of class M-3, as far as the mechanical properties are concerned, while their TS values were far below the standards. However, the British P3 interior fitment board criteria were satisfied at a dosing rate of 10% UF. The P4 load-bearing panel, however, required 12% of resin to satisfy the mechanical properties, while the TS remained a problem, even when the resin was increased to 14%.

It must be pointed out that no wax was used in the manufacturing of the boards. The addition of wax to reduce TS was investigated by adding 1 and 0.5% wax to the boards bonded with 12 and 14% resin, since these rates appeared to be promising in achieving the 8% and 14% TS value specified in the ANSI standard and in EN 312, for P4 load-bearing boards, respectively. The results are shown in Table 3. The addition of 0.5% and 1% wax to the boards bonded with 12% resin resulted in improved TS and satisfied the EN 312 standard, but still it was not sufficiently low to satisfy the ANSI standard. The only boards that conformed to the more stringent requirements (8% TS) were those bonded with 14% resin and 1% wax.

4 Conclusions

Bamboo chips were characterised by having higher length to thickness and length to width ratios and lower bulk density than industrial wood particles. The rate of heat transfer to the core was approximately the same in the two mats, probably reflecting the same values of bulk density between bamboo and wood chips. The results obtained in this study showed that bamboo chips can be successfully

Table 3 Mean properties of UF-bonded single-layer experimental particleboards. Standard deviations in parentheses
Tabelle 3 Mittelwerte der Eigenschaften von UF-gebundenen einschichtigen experimentellen Spanplatten. Standardabweichungen in Klammern

Resin (%)	Density (g/cm^3)	MOR (MPa)	IB (MPa)	TS (%)
10	0.754 (0.04)	13.85 (0.3)	0.62 (0.01)	23.1 (2.2)
12	0.749 (0.03)	16.66 (0.4)	0.79 (0.02)	17.3 (1.7)
14	0.743 (0.05)	18.98 (0.6)	0.95 (0.02)	14.7 (1.5)
12[1]	0.739 (0.04)	16.22 (0.5)	0.68 (0.02)	9.1 (1.1)
12[2]	0.752 (0.06)	16.46 (0.4)	0.74 (0.01)	13.2 (1.7)
14[1]	0.755 (0.06)	18.33 (0.4)	0.85 (0.02)	6.8 (0.7)
14[2]	0.748 (0.07)	18.64 (0.7)	0.90 (0.03)	11.3 (1)
ANSI A208.1-1998	Commercial use, shelving-M1	11.0	0.400	8
ANSI A208.1-1998	Industrial overlaying shelving, countertops-M2	14.5	0.450	8
ANSI A208.1-1998	Industrial overlaying shelving, stair treads-M3	16.5	0.550	8
EN 310 & EN 319	P2 general use	11.5	0.24	N/A
EN 310 & EN 319	P3 interior fitments	13.0	0.35	N/A
EN 310; 317; 319	P4 load bearing—dry	15.0	0.35	14

[1] Addition of 1% wax
[2] Addition of 0.5% wax

used, as an alternative lignocellulosic raw material, to manufacture P3 boards for interior fitments using a relatively low resin dosage (10% UF). The more stringent ANSI criteria, however, required 14% UF resin and 1% wax to satisfy the 8% TS criteria. Combinations of bamboo chips with industrial wood chips, application of other resin systems and the use of chemical modification (Papadopoulos and Traboulay 2002) may be an avenue for exploration in further investigations.

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